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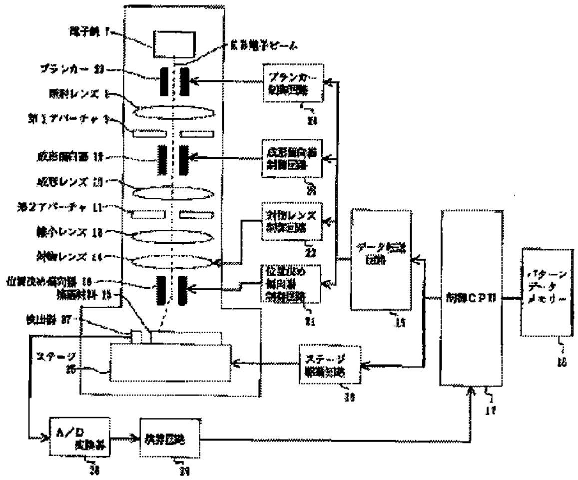
(54) [Title of the Invention] Method for focal adjustment of focused beam

(57) [Summary]

[Object] To provide a method for measuring a charged particle beam whereby the focusing state of a focused beam can be accurately measured without being affected by noise components.

[Means of Achievement] An electron beam is scanned across a knife edge member in a detector 27. The signal obtained from the detector 27 by means of this scanning is presented via an A/D converter 28 to an arithmetic circuit 29. In the arithmetic circuit 29, [a computation involving] subtracting one-half the initial value from the data, conversion to an absolute value, and addition is carried out. This computation is carried out while varying the excitation of an objective lens 14 multiple times. An optimal focal value is derived from the peak location of the resulting curve of the foci and the cumulative electric current values. Once a just-in-focus location has been derived, this value is presented by the arithmetic circuit 26 [sic] to a control CPU 18 [sic]. On the basis of the signal from the arithmetic circuit 26 [sic], the control CPU 18 [sic] controls an objective lens control circuit 22, and supplies the objective lens 14 with excitation current producing the just-in-focus state.



[7 electron gun; 8 irradiation lens; 9 first aperture; 10 shaping lens; 11 second aperture; 12 shaping deflector; 13 reducing lens; 14 objective lens; 15 lithographic material; 16 positioning deflector; 17 control CPU; 18 pattern data memory; 19 data transfer circuit; 20 shaping deflector control circuit; 21 positioning deflector control circuit; 22 objective lens control circuit; 23 blanker; 24 blanker control circuit; 25 stage; 26 stage drive circuit; 27 detector; 28 A/D converter; 29 arithmetic circuit; EB electron beam]

[Claims]

[Claim 1] A method for the focal adjustment of a focused beam, comprising:

scanning a focused beam across a member having a linear edge;

subtracting one-half the maximum signal amplitude from the signal detected in association with this scanning and adding the absolute value of the differential signal thereof, with the addition [operation] being carried out in each of several focal states of the focused beam while varying the focal state multiple times; and

on the basis of the result of multiple additions obtained thereby, adjusting the focused beam to the focus [observed] at the peak in the addition results.

[Claim 2] The method for the focal adjustment of a focused beam according to Claim 1, wherein

the focused beam is scanned across a knife edge member having a linear edge;

the beam not blocked by the knife edge member in this scan is detected;

one-half of the initial value of the signal is subtracted from the detected signal; and

the absolute value of the differential signal thereof is added.

[Claim 3] The method for the focal adjustment of a focused beam according to Claim 1, wherein

the focused beam is scanned across a member having a linear edge;

the signal reflected or generated from the member in association with this scan is detected;

one-half of the maximum value of the signal is subtracted from the adjusted signal after the detected signal has been adjusted to zero level; and

the absolute value of the differential signal thereof is added.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention] The present invention relates to a method for the focal adjustment of a focused beam used in an electron beam lithography apparatus, ion beam apparatus, or other apparatus that uses a beam of charged particles; or in a laser microscope or the like.

[0002]

[Background Art] In an electron beam lithography apparatus, for example, prior to carrying out the actual lithography procedure, the size and location of the electron beam used for patterning, or the focal state of the electron beam, are measured, and the electron beam is adjusted on the basis of the measurements. FIG. 1 depicts an example of an apparatus using an electron beam measurement of this kind, wherein 1 denotes the electron beam being measured. The electron beam 1 is shaped to a rectangular cross section by means of two rectangular slits and a deflector disposed between the slits (these are not illustrated in the drawing).

[0003] The electron beam 1 is focused by a final stage lens 2 and is then deflected by an electrostatic deflector 3. A knife edge member 4 is disposed below the electrostatic deflector 3; the knife edge member 4 has a rectangular opening and is formed with a thin linear shape at the inner [edges] thereof. Below the knife edge member 4 is disposed an aperture 5 for cutting scattered electron beams, and further below there is positioned a Faraday cup 6 for detecting the electric current magnitude of the electron beam.

[0004] With the above arrangement, when the sawtooth signal depicted in FIG. 2(a) is applied to the electrostatic deflector 2 [sic], the rectangular electron beam 1 is deflected towards the X direction. By means of deflecting the electron beam, the electron beam becomes gradually blocked by the knife edge member 4, and the magnitude of the electron beam incident on the Faraday cup 6 decreases. When the electron beam 1 becomes completely blocked by the knife edge member 4, the detected current of the Faraday cup 6 will go to zero.

[0005] FIG. 2(b) depicts the detected current of the Faraday cup 6, and the first derivative of the detected current signal gives the signal shown in FIG. 2(c). Further derivation of the signal shown in FIG. 2(c) gives the signal shown in FIG. 2(d). In FIG. 2(d), the horizontal axis represents the scanning location of the electron beam; the size of the electron beam is derived on the basis of the distance between the two peaks of the signal. The location of the electron beam is ascertained on the basis of the medial location between the two peak locations. The peak wave height value indicates the focal state of the electron beam. On the basis of the beam size, beam location, and focal state derived in this way, various adjustments are made to the electron beam, and subsequently the lithography operation itself is carried out.

[0006]

[Problems to Be Solved by the Invention] In measurement of the focal state and other characteristics of the electron beam described above, the detected signal shown in FIG. 2(b) typically includes noise components. FIG. 3(a) depicts a Faraday cup-detected signal that includes noise components, the first derivative of the signal including the noise components gives the signal shown in FIG. 3(b), and the signal obtained by the second derivative is as shown in FIG. 3(c). In the signal of FIG. 3(c), two peaks are embedded within noise peaks, and accurate measurement of focal state is impossible.

[0007] For this reason, a smoothing process is carried out on the signal. FIG. 4(a) depicts a detected signal that includes noise components; derivation of the signal gives the signal shown in FIG. 4(b). At this time, the first derivative signal is subjected to a smoothing process to eliminate noise. A second derivative that is obtained following this process gives the signal shown in FIG. 4(c). While correct peak locations are obtained with this signal, the peaks are blunted by the smoothing process, and the peak wave height values reflecting the focal state of the beam is not correct, making it substantially impossible to measure the focal state correctly.

[0008] With the foregoing in view, it is an object of the present invention to provide a method for measuring a charged particle beam whereby the focusing state of a focused beam cab be accurately measured without being affected by noise components.

[0009]

[Means Used to Solve the Above-Mentioned Problems] The method for the focal adjustment of a focused beam according to the first aspect of the present invention comprises scanning a focused beam across a member having a linear edge; subtracting one-half the maximum signal amplitude from the signal detected in association with this scanning and adding the absolute value of the differential signal thereof, with the addition [operation] being carried out in each of several focal states of the focused beam while varying the focal state multiple times; and, on the basis of the result of multiple additions obtained thereby, adjusting the focused beam to the focus [observed] at the peak in the addition results.

[0010] In the invention according to the first aspect, an electron beam is scanned across a member having a linear edge; one-half of the maximum signal amplitude of the signal is subtracted from the signal detected in association with the scan and the absolute value of the differential signal thereof is added, carrying out addition in each of several focal states of the

focused beam produced while varying the focal state multiple times; and the focused beam is adjusted to the focus [observed] at the peak in the addition results.

[0011] The method for the focal adjustment of a focused beam according to a second mode of the present invention comprises scanning the focused beam across a knife edge member having a linear edge; detecting the beam not blocked by the knife edge member in this scan; subtracting one-half of the initial value of the signal from the detected signal; and adding the absolute value of the differential signal thereof.

[0012] In the invention according to the second aspect, the focused beam is scanned across a knife edge member having a linear edge; and the beam not blocked by the knife edge member in this scan is detected. The method for the focal adjustment of a focused beam according to a third aspect of the present invention comprises scanning the focused beam across a member having a linear edge; detecting the signal reflected or generated from the member in association with this scan; subtracting one-half of the maximum value of the signal from the adjusted signal after the detected signal has been adjusted to zero level; and adding the absolute value of the differential signal thereof.

[0013] In the invention according to the third aspect, the focused beam is scanned across a member having a linear edge, such as a marking member positioned on the specimen; the signal reflected or generated from the member in association with this scan is detected; one-half of the maximum value of the signal is subtracted from the adjusted signal after the detected signal to zero level has been adjusted; and the absolute value of the differential signal thereof is added.

[0014]

[Embodiments of the Invention] Embodiments of the present invention will be described in detail below with reference to the accompanying drawings. FIG. 5 depicts an example of an electron beam lithography apparatus with a variable surface area. 7 denotes an electron gun for generating an electron beam EB. The electron beam EB generated by the electron gun 7 is directed onto a first shaping aperture 9 via an irradiation lens 8. An image of the aperture of the first shaping aperture 9 is focused by a shaping lens 10 onto a second shaping aperture 11, and the location of the focused image can be varied by means of a shaping deflector 12. The image formed by the second shaping aperture 11 is directed onto a lithographic material 15 through a reducing lens 13 and an objective lens 14. The location at which [the image] is directed onto the lithographic material 15 can be varied by means of a positioning deflector 16.

[0015] 17 denotes a control CPU. The control CPU 17 transfers pattern data from a pattern data memory 18 to a data transfer circuit 19. The pattern data from the data transfer circuit 19 is presented to a control circuit 20 for controlling the shaping deflector 12, a control circuit 21 for controlling the positioning deflector 16, a control circuit 22 for controlling excitation of the objective lens 14, and a blanking control circuit 24 for controlling a blanker (blanking electrode) 23 to perform blanking of the electron beam generated by the electron gun 7.

[0016] The control CPU 17 also controls a drive circuit 26 of the stage 25 for supporting the material 15 in order to move the material 15 on a field-by-field basis. A detector 27 is positioned at the edge of the stage 25; and the detector 27 is composed of the knife edge member 4, the aperture 5, and the Faraday cup 6 shown in FIG. 1.

[0017] The signal detected by the detector 27 is converted to a digital signal by an A/D converter 28 and is subjected to prescribed arithmetic operations by an arithmetic circuit 29. The results of the arithmetic operations by an arithmetic circuit 29 are presented to the control CPU 17. The operation of this sort of configuration will be described next.

[0018] First, the basic lithography operation will be described. Pattern data stored in the pattern data memory 18 is read out in succession and is supplied to the data transfer circuit 19. On the basis of the data from the data transfer circuit 19, the deflection control circuit 20 controls the shaping deflector 12 while the control circuit 21 controls the positioning deflector 16.

[0019] As a result, the cross section of the electron beam is formed into unit patterns by means of the shaping deflector 12 on the basis of the pattern data, and the unit patterns are then shot in succession onto the material 15 to pattern the material in the desired shape. During this time, the electron beam is blanked in sync with the shooting of the electron beam to the material 15, and the blanking is carried out by a blanking signal from the blanking control circuit 24 to the blanker 23.

[0020] During patterning onto different regions on the material 15, the stage 25 is moved prescribed distances by commands from the control CPU 17 to the stage drive circuit 26. The movement distance of the stage 25 is measured by a laser length measuring device (not shown), and the location of the stage is controlled accurately on the basis of length measurements from the length measuring device.

[0021] Next, measurement of the focal state of the electron beam directed onto the material 15 will be described. First, the CPU controls the stage drive circuit 26 to move the stage 25 and to

position the detector 27 below the optical axis of the electron beam EB. As in FIG. 1, the electron beam is scanned in this state across the knife edge member in the detector 27.

[0022] The scanning is carried out by supplying a scan signal from the positioning deflector control circuit 21 to the positioning deflector 16. The signal obtained from the detector 27 by means of this scan will have the signal waveform of FIG. 3(a), for example. This signal is presented to the arithmetic circuit 29 through the A/D converter 28.

[0023] The arithmetic circuit 29 imports this signal as *n* data [points] per scan. Scanning of the electron beam across the knife edge member and import of the signal are carried out while controlling the objective lens control circuit 22 from the control CPU 17 and varying the excitation level of the objective lens 14 in stepwise manner multiple times (*m* times). Signals represented by the following equations are imported to the arithmetic circuit 29 in association with the different varying excitation levels of the objective lens 14 (the change in electron beam focus).

[0024]

$$f_1(i) \quad i = 1, 2, 3, \cdots, n$$

$$f_2(i) \quad i = 1, 2, 3, \cdots, n$$

$$\vdots$$

$$f_m(i) \quad i = 1, 2, 3, \cdots, n$$

The waveforms of these signals are depicted in FIG. 6. In FIG. 6, the horizontal axis indicates the scanning location, and the vertical axis indicates the detected current value. The line L_1 shown as a solid line represents the waveform for a just-in-focus, the line L_2 shown as a double-dot and dash line represents the waveform when under-focused, and the line L_3 shown as a dotted line represents the waveform when over-focused.

[0025] Next, subtraction of one-half of the initial value I from the data, conversion to absolute values, and addition are performed in the arithmetic circuit 29 on the scan detection data. The operation is represented by the following equation.

[0026]

[Eq. 1]

$$F_1 = \sum_{i=1}^{n} \left| f_1(i) - f_1(1)/2 \right|$$

$$F_2 = \sum_{i=1}^{n} \left| f_2(i) - f_1(2)/2 \right|$$

$$\vdots$$

$$F_m = \sum_{i=1}^{n} \left| f_m(i) - f_m(1)/2 \right|$$

[0027] FIG. 7 depicts waveforms of signals [derived from] scan detection data by subtraction of one-half of the initial value I from the data and conversion to absolute values (i.e. signal waveforms prior to the addition process). In FIG. 7, the horizontal axis indicates the scanning location, and the vertical axis indicates the detected current value. The line L_4 shown as a solid line represents the waveform for a just-in-focus, and the line L_5 shown as a single-dot and dash line represents the waveform during under-focus and during over-focus.

[0028] When addition is performed for the waveforms depicted in FIG. 7, the effect of noise components contained in the signals can be eliminated. Specifically, for random noise components or cyclical noise components whose cycle is sufficiently shorter than the scan time, the sum of these will approach zero. Even for cyclical noise components with longer cycles, the effect on the results of addition will be the same as long as their phases are aligned, and accurate focusing information can be obtained. As a result, only the focal information will remain correct in the addition results.

[0029] In cases in which the waveforms depicted in FIG. 6 are simply added without being modified in any way, it will not be possible to selectively obtain focal information only. Specifically, the just-in-focus curve has the highest electric current magnitude in proximity to the initial inflection point P1 of the signal waveforms, and the electric current magnitude of the under-focus and over-focus curves is lower than the electric current magnitude of the just-in-focus curve.

[0030] On the other hand, the just-in-focus curve has the lowest electric current magnitude in proximity to the second inflection point P2, and the electric current magnitude of the under focus and over focus curves is higher than the electric current magnitude of the just-in-focus curve. Consequently, if signals having two inflection points are simply added, there will be a difference in the results of addition between the just-in-focus [state] and the other focal states.

[0031] In consideration of the above, in the present invention, [an operation of] subtracting one-half of the initial value I from the data and deriving the absolute value thereof is performed on the detection signals on the basis of scanning conducted using the electron beam, so that the values of the just-in-focus curve at the inflection points P1, P2 in the curves shown in FIG. 7 are always greater than the values in the under-focus and over-focal states.

[0032] In each focal state it will thus be possible to impart variation to the results of addition. The results of addition in each focal state will therefore be a curve similar to that shown in FIG.

8. In FIG. 8, the location with the largest addition value is the just-in-focus location. In the example shown in FIG. 6, the beam was scanned across the knife edge member. In this example, the maximum amplitude value of the detection signal will be the initial value of the signal since the detection signal goes to zero at the point in time that the beam is entirely blocked by the knife edge.

[0033] For the curve of FIG. 8, a second-order curve approximation F(x) is performed on the curve of foci and added current values by the method of least squares to derive an optimal focal value from the peak location. This operation is executed by the arithmetic circuit 29. When deriving the peak value, some other approximation method besides second-order approximation could be used instead. Where scanning of the electron beam at varying foci has been carried out a relatively large number of times and the number of plots is relatively large, it will not be necessary to use curve approximation.

[0034] Once the series of processes described above has been carried out and the just-in-focus location has been determined, the value is presented to the control CPU 18 [sic] by the arithmetic circuit 26 [sic]. On the basis of the signal from the arithmetic circuit 26 [sic], the control CPU 18 [sic] controls the objective lens control circuit 22 and supplies the objective lens 14 with excitation current to produce the just-in-focus [state]. Subsequently, the control CPU 18 [sic] sends the lithography data to the data transfer circuit 19, and the lithography process itself is carried out on the material 15.

[0035] While the invention has been shown hereinabove in terms of a certain preferred embodiment, the invention is not limited to this embodiment. For example, while [in the preceding embodiment] the electron beam was blocked by the knife edge member 4 while the magnitude thereof incident on the Faraday cup 6 was detected, it would be acceptable to instead have an arrangement employing a linear-edged material having a high emission coefficient of secondary electrons or reflection electrons, and to scan a charged particle beam across the material while detecting secondary electrons or reflection electrons. In this case, the detection signal would be as shown in FIG. 9 (a).

[0036] In this case, the lowest level of the detection signal would be assigned zero level as shown in FIG. 9 (b), and subsequently one-half of the maximum amplitude value I of the detection signal would be subtracted, and the absolute value of the signal of FIG. 9 (b) would be derived as shown in FIG. 9 (c). In the signal waveforms depicted in FIG. 9, the line indicated by

the solid line is that for the just-in-focus state, and the line indicated by the dotted line is that for the under-focus and over-focal states.

[0037] While the preceding embodiment described the use of an electron beam, implementation would be analogous in a case in which the focal state of a focusing ion beam or focusing laser beam is measured.

[0038]

[Effect of the Invention] As described hereinabove, the invention according to the first aspect comprises scanning a focused beam across a member having a linear edge; subtracting one-half the maximum signal amplitude from the signal detected in association with this scanning and adding the absolute value of the differential signal thereof, with the addition [operation] being carried out in each of several focal states of the focused beam while varying the focal state multiple times; and, on the basis of the result of multiple additions obtained thereby, adjusting the focused beam to the focus [observed] at the peak in the addition results. As a result, the effects of noise in the detection signal can be markedly reduced during measurement of the focal state of the focused beam, and accurate adjustments of the focus of the focused beam can be made.

[0039] In the invention according to the second aspect, the focused beam is scanned across a knife edge member having a linear edge; and the beam not blocked by the knife edge member in this scan is detected, thereby affording effects similar to those of the invention according to the first aspect.

[0040] In the invention according to the third aspect, the focused beam is scanned across a member having a linear edge, such as a marking member positioned on the specimen; the signal reflected or generated from the member in association with this scan is detected; and one-half of the maximum value of the signal is subtracted from the adjusted signal after the detected signal to zero level has been adjusted; and the absolute value of the differential signal thereof is added, thereby affording effects similar to those of the invention according to the first aspect.

[Brief Description of the Drawings]

[FIG. 1] A diagram showing an example of a conventional device used for electron beam measurement.

[FIG. 2] A waveform diagram illustrating basic signal processing for electron beam measurement.

[FIG. 3] A diagram of various waveforms in conventional signal processing.

[FIG. 4] A diagram of various waveforms in conventional signal processing conducted in association with a smoothing process.

[FIG. 5] A diagram depicting an example of an electron beam lithography apparatus having a variable surface area.

[FIG. 6] A diagram depicting signal waveforms in each focal state.

[FIG. 7] A diagram depicting signal waveforms derived from the signals in FIG. 6 by subtracting one-half the initial value and taking the absolute value.

[FIG. 8] A diagram depicting change in added value of the signals of FIG. 7 in each focal state.

[FIG. 9] A diagram depicting signal waveforms in another embodiment of the invention.

[Key]

7 electron gun

8 irradiation lens

9 first aperture

10 shaping lens

11 second aperture

12 shaping deflector

13 reducing lens

14 objective lens

15 lithographic material

16 positioning deflector

17 control CPU

18 pattern data memory

19 data transfer circuit

20 shaping deflector control circuit

21 positioning deflector control circuit

22 objective lens control circuit

23 blanker

24 blanker control circuit

25 stage

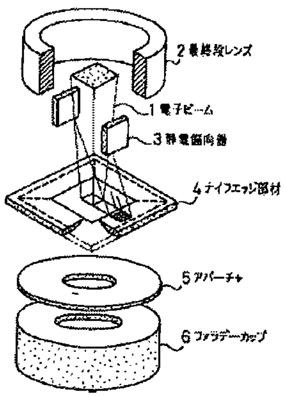
26 stage drive circuit

27 detector

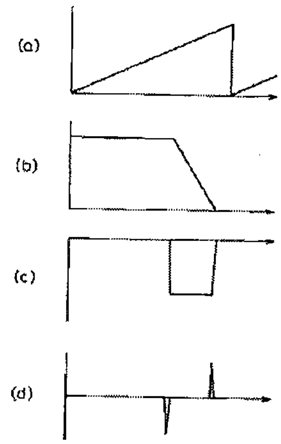
28 A/D converter

29 arithmetic circuit

[FIG. 1]

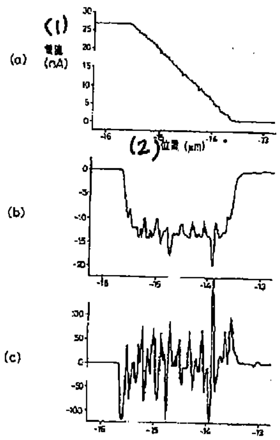


[FIG. 2]

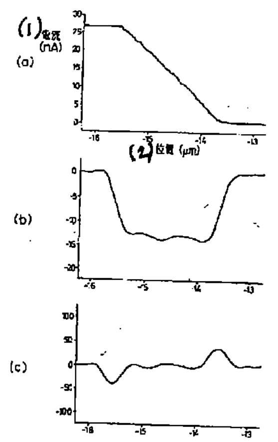


[1 electron beam; 2 final stage lens; 3 electrostatic deflector; 4 knife edge member; 5 aperture; 6 Faraday cup]

[FIG. 3]

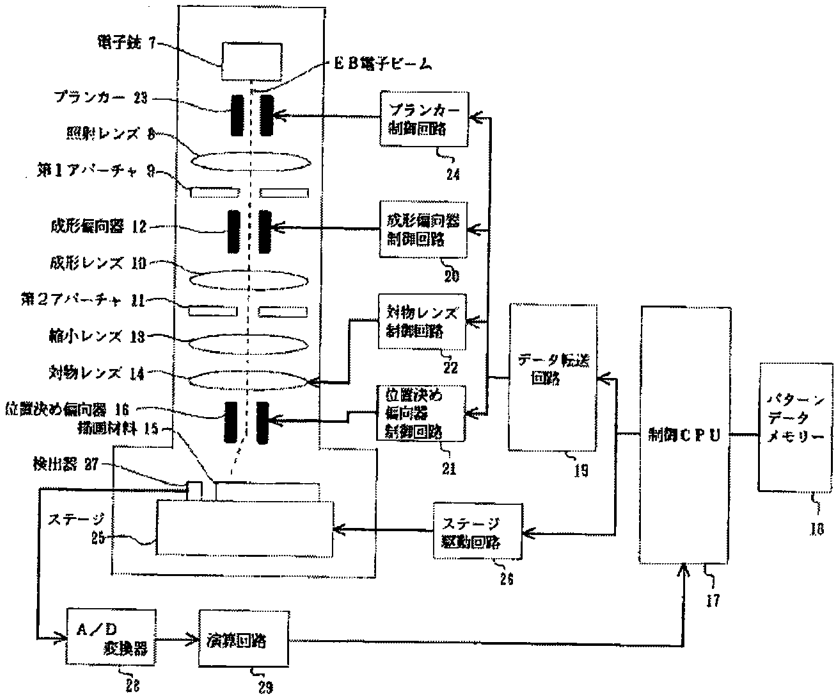


[FIG. 4]



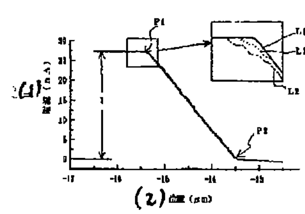
[(1) current; (2) location]

[FIG. 5]

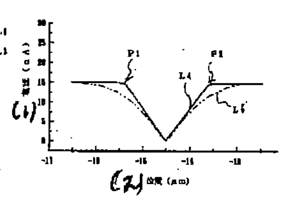


[7 electron gun; 8 irradiation lens; 9 first aperture; 10 shaping lens; 11 second aperture; 12 shaping deflector; 13 reducing lens; 14 objective lens; 15 lithographic material; 16 positioning deflector; 17 control CPU; 18 pattern data memory; 19 data transfer circuit; 20 shaping deflector control circuit; 21 positioning deflector control circuit; 22 objective lens control circuit; 23 blanker; 24 blanker control circuit; 25 stage; 26 stage drive circuit; 27 detector; 28 A/D converter; 29 arithmetic circuit; EB electron beam]

[FIG. 6]

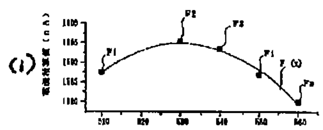


[FIG. 7]



[(1) current; (2) location]

[FIG. 8]



[(1) added current value]

[FIG. 9]